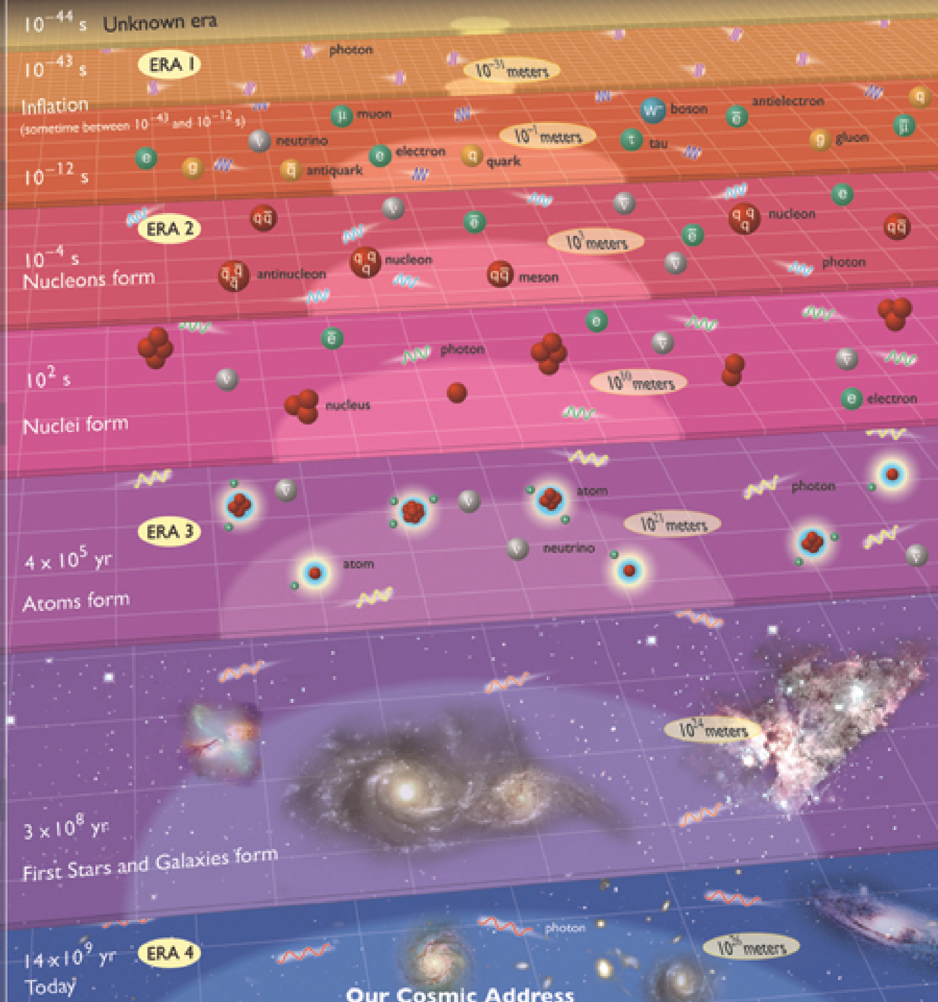
THE HISTORY AND FATE OF THE UNIVERSE

Four eras and eight major stages in the evolution of the universe

The Big Bang occurred everywhere in the universe. Here one region has been illuminated and followed through time. The expansion is far greater than can be shown here.



The Big Bang and Expanding Universe

Space is expanding from an initial moment called the Big Bang. As it expands, the universe becomes less dense and cools. All distant galaxies are moving apart from each other and away from us. On large scales, the universe looks the same in all directions and in all parts of space. There is no center. Our current understanding of the early universe is called the Big Bang model. We are continuing to learn from astronomical observations and from accelerator-based experiments.

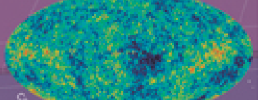
History of the Universe

Cosmology and Relics of History

Cosmology is the study of the universe as a whole. As in archaeology, cosmology finds clues to the past in relics. We can look back in time by looking out in space. Since light travels at a finite speed c, the time t we are looking back is $t = d/c$, where d is the distance. The laws of nature discovered on Earth are applied to the early universe and tested by observing relics.

A Relic from the Early Universe

The Cosmic Microwave Background (CMB) is a universal bath of lightwaves (photons) from the hot, dense, early universe. To one part in 100,000, the CMB is the same no matter where you look. The remaining tiny variations in the density of mass-energy (shown in figure) are seeds that later form galaxies and larger cosmic structures.



This is an image of the universe from the time when atoms first formed. It is a map of the entire sky showing CMB light with the uniform part subtracted.

Age of the Universe

Studying the cosmic microwave background, the expansion of the universe, and the life cycles of stars leads to a marvelous agreement that the age of the universe is about 14 billion years (14×10^{9} years).

Four major eras in the expansion history:

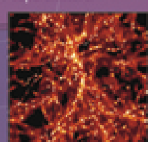
Era 1 – Acceleration: Inflation Speeds Expansion

Observations seem to imply that the very early universe underwent an extremely rapid, accelerating expansion, called *inflation*. In a tiny fraction of a second, inflation expanded each part of space by a factor of at least 10^{26}. Before inflation, the portion of the universe visible to us today was a smooth patch much smaller than a proton. As inflation ended, the visible universe had grown (very approximately) to the size of a ball.

Eras 2-3 – Deceleration: Expansion Slows and Structure Forms

After inflation, the universe was a soup of fundamental particles, called a quark-gluon plasma. Photons and fast moving particles, generically called radiation, gradually lost energy (cooled) as the universe expanded (the energy went into the expansion). Eventually, slow-moving matter became dominant over radiation. Over time, larger and larger structures grew, from galaxies to clusters of galaxies to superclusters.

Simulation of matter distribution in the early universe that eventually yielded galaxies and clusters of galaxies.



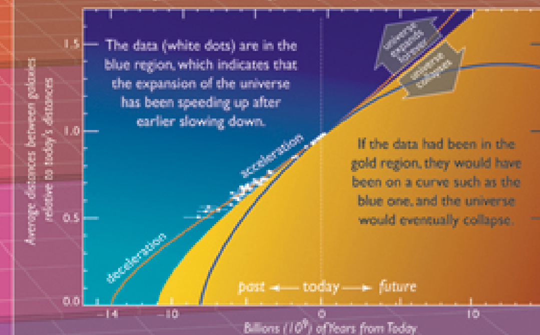
Era 4 – Acceleration: Dark Energy Speeds Expansion

Astronomers had assumed that the current universe is dominated by matter, which would cause deceleration and might even reverse the expansion. So it was a great surprise in 1998 when observations showed that the expansion of the universe is now accelerating (see the "Accelerating Universe" plot). This implies the existence of a bizarre new form of energy, referred to as *dark energy*.

The Accelerating Universe

By observing other astronomical relics, distant exploding stars called supernovae, astrophysicists are digging ever further back into the history of the universe.

The plot shows data (white dots) from distant supernovae. The orange curve, with the best fit to the supernovae data, shows that billions (10^{9}) of years ago the expansion of the universe began to accelerate (the data curve upward slightly). This acceleration is attributed to a new form of energy called "dark energy" that pulls space apart.



Before the supernova research, physicists believed that the whole expansion history of our universe would lie in the gold region, where the expansion would be slowed by the attractive force of gravity. Now we see from the supernova data that the expansion history lies in the blue region, where attractive and repulsive forces compete for dominance.

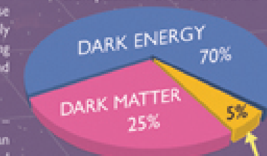
The Fate of the Universe

Whether the expansion of the universe will speed up, slow down, or even possibly reverse into collapse depends (according to gravitation theory) on the amount and types of matter and energy in it.

The ordinary matter – atoms and nuclei – that formed in the early universe can account for the visible mass in galaxies and clusters. But the amount of ordinary matter is a tiny fraction of the total mass needed to bind a galaxy or cluster together gravitationally and explain its internal motions. So an extraordinary new type of matter, not made of atoms or nuclei, must exist; it is called *dark matter* because it is not directly visible.

Even stranger, recent observations of supernovae in distant galaxies show that the expansion of the universe is in fact accelerating. An exotic dark energy may be causing this acceleration through a cosmic repulsion that overwhelms the pull of gravity due to matter.

Composition of the Universe



The nature of dark energy and dark matter are two of the great questions facing cosmology and particle physics. Perhaps dark energy is the cosmological constant, introduced by Albert Einstein in 1917. Perhaps both are new parts of particle physics, tied to the very earliest moments of the universe and having to do with the nature of physics and spacetime itself.

Not all answers in science are known yet! With research and experiments under way in astrophysics, particle physics, and nuclear physics, we may be the first generation to learn what most of the universe is made of and what is the fate of the universe.

Our Cosmic Address

Our sun is one of 4×10^{11} stars in the Milky Way galaxy, which is one of more than 10^{9} galaxies in the visible universe.

Learn more at UniverseAdventure.org and at CPEPweb.org

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This chart has been made possible by the generous support of: **U.S. Department of Energy, U.S. National Science Foundation, Lawrence Berkeley National Laboratory, SNAP-SuperNova/Acceleration Probe, CERCA-Case Western Reserve University.** Photos courtesy of **NASA.**